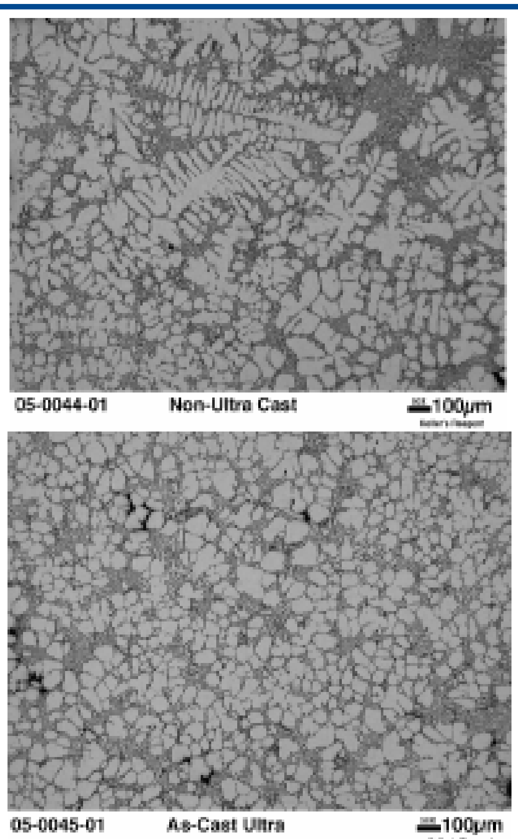
Ultrasonic Processing of Materials

Presence of High-Intensity Ultrasonic Vibration Enhances Degassing in Melting and Grain Refinement in Casting

Ultrasonic effects on the microstructure of alloys are multi-faceted and include reduction in the grain size, control of columnar structure, formation of equiaxed grains, improvement of material homogeneity, segregation control, and the uniform distribution of second phases and inclusions. Although many studies of the use of ultrasonic energy during solidification have been carried out in the laboratory, there has been limited industrial-scale application. In addition, there have been no fundamental studies on the effects of ultrasonic vibration on the nucleation and growth of grains during solidification. The project team identified an opportunity to improve energy efficiency by evaluating the core principles and establishing quantitative bases for the ultrasonic processing of materials.

The project team demonstrated key applications in the areas of grain refinement of alloys during solidification and degassing of alloy melts. The results demonstrated that ultrasonic processing can be used to produce spherical grains that are smaller than those produced with the most powerful grain refiners. Furthermore, materials with these spherical grains are suitable for semisolid metal processing, a new processing technology for producing high-quality components for critical applications. The experimental results suggest that ultrasonic processing has the potential for a more energy-efficient scale up for the production of critical metal components, leading to cost reductions, energy savings, and many other benefits.



The top figure shows the microstructure of A354 alloy without exposure to ultrasonic vibration (note the fully developed dendrites) and the bottom figure shows the microstructure resulting from the exposure to ultrasonic energy.

Benefits for Our Industry and Our Nation

Ultrasonic processing can be used to improve the mechanical properties of castings. This technology has the advantage of better energy efficiency compared to traditional technologies, including the use of grain refiners.

Applications in Our Nation's Industry

The project results have the potential to impact a wide range of alloy processing technologies, including direct chill (DC) casting, continuous casting, vacuum arc remelting, and foundry processing in the areas of degassing, grain refinement, and the production of new and novel microstructures. The project will benefit the following industries:

- Steel
- Aluminum
- Metal Casting
- Forging

Project Description

The objectives of this project included (a) obtaining a better understanding of the effect of ultrasonic energy on the degassing of liquid metals during melting and on microstructure modification during solidification, and (b) development of unique approaches for producing ultrafine grains and novel microstructures during the solidification of alloys.

Barriers

Although many studies on the use of ultrasonic energy during solidification have been carried out in the laboratory, there has been limited industrial-scale application. In addition, there have been no fundamental studies on the effects of ultrasonic vibration on the nucleation and growth of grains during solidification.

Pathways

The following tasks were envisioned and carried out:

- Designed and built an experimental apparatus for various ultrasonic processing methods
- Demonstrated degassing of aluminum alloys using ultrasonic energy
- Demonstrated thermodynamic simulation of the solid fraction vs. temperature curves of aluminum alloys and steel alloy using the Scheil model
- Performed solidification of alloys in an acoustic field
- Characterized specimens solidified under the influence of ultrasonic energy
- Evaluated grain refinement and spherical grain formation of various solid fractions of the solidifying alloys injected with ultrasonic energy
- Determined parameters for industrial applications of ultrasonic processing

Results

The introduction of ultrasonic energy is very useful for degassing and grain refinement of 4340 steel and many aluminum alloys, including A356, A354, 319, 3004, 6061, and 6063. A patent application titled *Method and Apparatus for Semi-Solid Material Processing* has been filed.

The following are the results of this project:

- Demonstrated that with continuous presence of ultrasonic vibration in solidifying specimens, fine globular grains were obtained instead of large dendritic grains. Under some conditions, the size of the primary aluminum grains reached 20 micrometer (μm), which is much smaller than the size of few millimeters obtainable without ultrasonic vibration. Also, the morphology and the size of the eutectic silicon phase were altered. The length of eutectic silicon was about 1μm in specimens treated ultrasonically, as opposed to 30 μm in specimens prepared without ultrasonic vibration.
- Demonstrated that with increasing ultrasonic amplitude, the primary aluminum grains became less dendritic and more spherical. Also, the size and morphology of the eutectic silicon phase were altered from coarse and acicular or lamellar to a fine fibrous form. High ultrasonic amplitude favored the formation of small, spherical aluminum grains.
- Demonstrated that the size of the primary aluminum grain decreased with decreasing casting temperature, reached a minimum at 630^{o}C, and then increased slightly with slightly decreasing casting temperature.
- Investigated degassing of A356 alloy under ultrasonic vibration and obtained a steady-state hydrogen concentration within a few minutes, regardless of the initial hydrogen concentration in the melt.
- Demonstrated that ultrasonic vibration can be used to reduce porosity formation in aluminum alloys and with increasing processing time, the porosity can be decreased significantly.

Commercialization

The project team is continuing to look for industrial partners with an interest in the next stage of scale-up of this technology.

Project Reports

This project was completed in December 2004. The final report is available on the Industrial Technologies Program website: http://www.eere.energy.gov/industry/imf/completed_rd.html

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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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